King's Research Portal

DOI:
10.1038/s41598-018-32865-6

SCIENTIFIC REPORTS

OPEN

Sensitivity to CT-optimal, Affective Touch Depends on Adult Attachment Style

Received: 2 March 2018
Accepted: 6 September 2018
Published online: 28 September 2018

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Affective touch supports affiliative bonds and social cognition. In particular, gentle, stroking touch, which has recently been associated with the C Tactile (CT) system, is typically perceived as pleasant and prosocial. However, it remains unknown whether pre-existing models of social relating influence the perception of CT-optimal touch. In this study ($N = 44$ adults), we examined how individual differences in attachment styles relate to the perception of CT-optimal touch, as well as to a different modality of interoception, namely heartbeat perception. Using the gold-standard assessment of attachment (Adult Attachment Interview), we found that insecure attachment was associated with reduced pleasantness discrimination between CT-optimal vs. non-CT optimal touch. Acknowledging the different traditions in measuring attachment, we also used a well-validated self-report questionnaire that pertains to explicit representations of current close relationships. Using this measure, we found that higher scores in attachment anxiety (but not attachment avoidance) were associated with reduced pleasantness discrimination between CT-optimal vs. non-CT optimal touch. Attachment patterns (in both measures) were not related to cardiac perception accuracy. These results corroborate and extend previous literature on CT-optimal touch and its relation with affiliative bonds and social cognition. Given that attachment was not related to perceived cardiac accuracy, these findings point to the specificity of the relationship between CT-optimal touch and attachment.

Attachment theory is one of the most influential theories of the development of close social relationships[1,2]. Its key tenet is that infants have an innate drive to form a close bond with their primary caregivers to ensure their survival and well-being in times of threat. In the past decades, the emphasis in attachment research has been influenced by the additional, cognitive hypothesis that differences in the responsiveness and availability of caregivers to the infant's attachment needs lead to the development of internal working models of social relating and associated affect regulation strategies[3]. These working models are described as affective-cognitive schemas, termed 'attachment representations' or most generally referred to as attachment styles, that are transferred from parental figures to romantic relationships[4] and remain relatively stable across the life span[5]. For example, secure attachment is characterized by positive views of self and other, and the belief that one can turn to others for support and those others will be responsive[6].

The emphasis on these internal working models in attachment theory has somewhat shifted attention away from Bowlby's original focus on physical 'proximity seeking' as the primary behavioural strategy for coping with threat (in a wider sense)[1,2]. Crucially, a central aspect of proximal caregiving during threat is touch. Touch is the first of our senses to develop[7], setting the stage for one of the earliest maternal interactions[8], as well as being a necessary part of caregiving interactions[9,10]. In non-human mammals, it has long being established that touch between conspecifics has evolved to promote not only caregiving but also stress regulation and affiliative bonding[11], with well-studied neurophysiological, genetic, and epigenetic mechanisms[12–14]. Interestingly, idiosyncratic differences in maternal tactile behaviours lead to individual differences in rats' behavioural and neuroendocrinal responses to stress during adulthood[15].

There is also increasing understanding about the role of touch in promoting affiliative bonds, affect regulation, and healthy development in humans (e.g.,[10,16]), while early social and tactile deprivation have corresponding

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detrimental effects (e.g.[17,18]). Specifically, following on from the animal literature, research has explored the impact of maternal touch on human infants' emotion regulation and particularly on stress responses (e.g.[19]). Moreover, the effects of touch on cognitive and affective development extend to self-awareness (e.g.,[20,21]) and social learning. For instance, touch is a particularly effective way of directing infant attention[22,23] and a particularly effective cue for increasing infants' appropriate eye-contact behaviours[24]. Finally, the effects of touch on brain development have been examined recently. Evidence suggests that there is an association between the frequency of maternal touch during mother-infant interactions and functional connectivity in various nodes of the infants' default mode network, thought to support self-awareness and social cognition[16].

Despite this progress in infant research, however, less is known about any lasting effects of such early tactile interactions, and particularly the relationship between individuals' life-long attachment style and their reactivity to social touch. The primary aim of the present study was the investigation of this relationship, and particularly the investigation of how individual differences in adult attachment style may affect the perception of a neurophysiologically specific type of touch that has been shown to be highly relevant in close relationships. Specifically, while there are many different types of social touch, varying in terms of physiological parameters, the caress-like, slow velocity, moving touch on the skin, termed '*affective touch*' or ' *interoceptive touch*' due to its well-studied positive affective value[25], has been shown to convey social support and intimacy with greater specificity than other types of social touch[26,27]. Specifically, in adults, slow, gentle stroking touch, as compared with fast stroking touch, has been shown to specifically communicate social intimacy and support[26], to reduce experimentally-induced feelings of social rejection[27] and subjective and neural responses to noxious stimulation[28], as well as to contribute uniquely to embodied facets of self-awareness[29–31]. Critically, a specialized system of unmyelinated nerve fibres called C-tactile (CT) afferents is thought to respond optimally to this type of touch[32]. CTs are found only in hairy skin[32], respond well to low force stroking[33], and are velocity[34] and temperature[35] tuned. Specifically, CTs' mean firing rate is higher in response to relatively slow velocity tactile stimulation (1–10 cm/s^{-1}) and lower in response to velocities above or below this range, suggesting that stroking within the 1–10 cm/s range optimally activates CT afferents. The activation of CTs (i.e., their mean firing frequency) is strongly correlated with perceived pleasantness, suggesting a relationship between positive hedonic sensation and coding at the peripheral level[34]. Moreover, neuropsychological[26,36,37], neuroimaging[38–41,] and neuromodulation[42] studies on the perception of CT-optimal touch have shown selective involvement of brain networks that have been associated with the processing of interoceptive signals, that is, signals regarding the physiological condition of the body (i.e., posterior insular cortex[38], orbitofrontal cortex[39,] and anterior cingulate cortex[40,41]; see also[43,44] for reviews and[45] for a meta-analysis).

Accordingly, it has been hypothesized that CT-fibers are the peripheral end of a dedicated interoceptive tactile system supporting the affective and affiliative functions of touch[32,46]. Nevertheless, the relationship between CT-optimal stimulation, autonomic regulation, and interoception remains unclear in adults, as CT-optimal touch is specifically associated with reductions in cardiac reactivity and skin conductance responses[47], but not other measures of autonomic reactivity, such as cortisol variability[48], or interoceptive awareness such as cardiac accuracy[30]. One possible explanation for the lack of relationship between interoceptive measures such as cardiac accuracy and affective touch perception is that such measures do not typically account for top-down factors (cognitive beliefs, styles and expectations). Indeed, to our knowledge, the relationship between the perception of this tactile modality, as well as other interoceptive modalities such as cardiac accuracy, and attachment style remains unexplored.

Therefore, this study aimed to characterize individual differences in CT-optimal touch and cardiac accuracy in terms of differences in pre-existing models of social interactions, namely attachment styles. Specifically, if CT-optimal touch is an interoceptive modality particularly relevant to social affiliation and affect regulation, one can presume that the perception of this specific type of touch in adulthood can further depend on individual differences in attachment. As pre-existing affective-cognitive models of social relating, individual differences in attachment style could determine the top-down influences on the perception of CT-optimal touch. Such findings exist in other interoceptive modalities such as hunger[49] and pain (reviewed by[50,51]), the latter being an interoceptive modality with opposite hedonic (positive vs. negative valence) and social (care vs. harm) characteristics to affective touch (see[52] for discussion). For example, chronic pain is more common in individuals with insecure rather than secure attachment styles[50]. We have also previously shown that the effects of social support on subjective, physiological, and neural responses to pain, including support conveyed by CT-optimal touch[28], depend on individual differences in attachment style[28,53,54].

However, to our knowledge, the relationship between attachment style and sensitivity to CT-targeted touch has not yet been studied. Here, we extend previous literature to examine how attachment style relates to the perception of CT-optimal versus non-CT optimal touch, as well as to a different non-social modality of interoception, namely cardiac accuracy. Specifically, acknowledging the different research traditions in measuring attachment (see[55] for a review), we examined attachment using two different measures. First, we administered the gold-standard Adult Attachment Interview (AAI[56]). Taking a categorical approach, this semi-structured interview yields secure vs. insecure attachment classifications (as well as further sub-classifications of attachment characteristics) on the basis of questions relating to childhood experiences with caregivers. In addition, we used a well-validated self-report questionnaire (the Experiences in Close Relationships Revised questionnaire[57]). This questionnaire pertains to adult romantic relationships and takes a dimensional rather than categorical approach, yielding continuous scores of attachment anxiety and avoidance. Attachment anxiety is characterized by a need for emotional closeness, worries of rejection and abandonment, over-dependence on others, negative views of self, positive views of others, and high emotional reactivity. Attachment avoidance is characterized by a need for emotional distance, resistance to trusting and depending on others, positive views of self, negative views of others, and suppression of emotion.

Given their history in seeking comfort through proximity, we expected that securely attached individuals, based on a categorical AAI classification, would find CT-optimal touch (i.e., delivered at CT-optimal speeds, 1–10 cm/s) more pleasant than non-CT optimal touch (delivered at non-CT-optimal speeds, below and above 1–10 cm/s). By contrast, yet in line with previous findings on tactile exposure[58], we expected that insecurely attached individuals (associated with reduced proximity-seeking in the case of dismissive attachment, or truly obtaining comfort through proximity, including touch, in the case of preoccupied attachment) would be less sensitive to CT-targeted touch, that is, they would show reduced perceived pleasantness discrimination between the two types of touch. Exploring such differences further using a continuous measure of adult attachment style, we expected that this reduced sensitivity to the hedonic effects of CT-optimal and non-CT-optimal touch would be especially pronounced in individuals scoring higher in anxious and avoidant attachment dimensions, given their typical negative feelings and beliefs about seeking or receiving social support[59].

In addition, to investigate whether the relationship between insecure attachment and CT-touch sensitivity is specific to this modality, or whether it relates to all interoceptive domains, we also employed a widely-used task of heartbeat counting as a measure of 'interoceptive accuracy', a particular facet of interoceptive awareness (see[60]). Given previous findings about the dissociation between cardiac accuracy and CT touch[30], we expected that attachment style, as measured by both categorical and continuous measures, would not relate to cardiac perceived accuracy as measured by the standard heartbeat perception task, confirming the specificity of CT-optimal touch to social bonding and attachment.

Method

Participants were $N = 44$ right-handed women aged 18–31 years old ($M = 23.87$, $SD = 3.77$), recruited from King's College London and University College London. Participants did not currently suffer from and/or have a history of psychiatric disorders, neurological or medical conditions, and did not have wounds, scars, tattoos or skin irritation/diseases on their forearms. Participants were invited to take part in a study on bodily self-awareness consisting of two separate parts: one part involved rating the pleasantness of touch administered by the experimenter at different velocities (the touch paradigm; see below) and an interoceptive accuracy (heartbeat perception) task. The other part comprised the adult attachment interview, and participants also completed the Experiences in Close Relationships Revised questionnaire (ECR-R[57]) a self-report measure of adult attachment style. Participants' numerical IDs were used to match data from the different parts of the study, and written informed consent was obtained from all participants. The Chair of the Research Department of Clinical, Educational and Health Psychology, University College London (UCL), approved this study, and the experiment was conducted in accordance with the Declaration of Helsinki.

Touch paradigm.

A trained experimenter unknown to participants manually stroked participants' left forearm using a cosmetic make-up brush (Natural hair Blush Brush, No 7, The Boots Company). Participants were seated comfortably at a computer, with their left forearm rested at an approximate 45° angle in front of them (their palm facing upwards) but separated from their view by means of a curtain. Two 9 cm long by 4 cm wide areas were marked continuously along participants' left volar forearm between wrist and elbow. To ensure a constant pressure, the brush splayed no wider than the 4 cm window. Touch was administered to the underside of participants' left forearm in an elbow-to-wrist direction[61,62] at four different velocities, administered in a pseudo-randomized order and alternating between skin areas to avoid habituation: two CT-optimal speeds i.e., 3 cms^{-1} (3 strokes per interval) and 9 cms^{-1} (9 strokes) and two non-CT-optimal speeds i.e., 0.3 cms^{-1} (1 stroke covering 2.7 cm in the middle of the 9 cm window) and 27 cms^{-1} (27 strokes). Each velocity was administered for 9 s, followed by a 30-second interval during which participants rated the pleasantness of the touch on a visual analogue scale from −100 (very unpleasant) to 100 (very pleasant) on a computer. Each velocity was administered three times, and a mean rating was calculated for each velocity.

Interoceptive accuracy.

We measured interoceptive accuracy using the heartbeat perception task[63]. Participants' heart rate was recorded using MP150 Data Acquisition Hardware (BIOPAC Systems Inc). A heartbeat monitor was attached to the tip of the left index finger and checked for tightness so that participants could not feel a pulse at this site. During a short training session participants were instructed to report the number of perceived heartbeats within a 15-second time interval. They were explicitly told to only count and report the number of actually perceived (and not estimated) heartbeats. The experiment started with a 10-second resting period. Participants closed their eyes and then silently counted their heartbeat (keeping their hand still and without feeling their pulse) for three trials lasting 25 seconds, 35 seconds and 45 seconds; the order was pseudo-randomised and participants were not informed of the duration of each trial. The beginning and end of each counting interval was signaled via tones. There was a 20-second pause after each trial during which participants verbally indicated their count for each trial. Interoceptive accuracy was computed using the mean score of the three heartbeat counting trials, using the transformation detailed in[63] (see formula also below).

$$(1 \div 3) \times \sum_{i=0}^{3}[1 - ((recorded\ items - counted\ items) \div recorded\ items)]$$

This yields a score between zero and one, with one denoting greater correspondence between actual and perceived number of heartbeats (i.e., higher interoceptive accuracy).

Adult attachment interview (AAI).

The AAI is a semi-structured interview, including 20 questions and lasting up to circaone hour[56]. Meta-analyses and psychometric testing indicate stability, and discriminant and predictive validity in both clinical and non-clinical populations[55,64–66]. Participants were asked to reflect about their childhood experiences and early relationships with parents/caregivers. Questions included whether participants had experienced loss, separation, or rejection, how their caregiver typically responded in particular

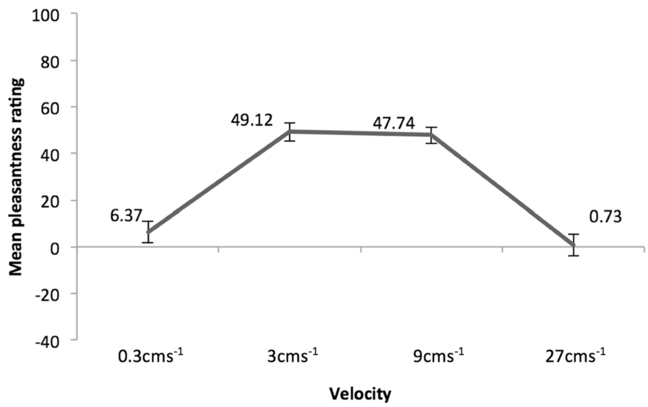

Figure 1. Pleasantness ratings for the four touch velocities. Scale range: −100 to 100. Error bars denote ±1 standard error of the mean.

situations (e.g., when the participant was upset), and the kinds of implications these experiences had for the participant's adult life (see[64] for a detailed introduction to the AAI). All interviews were audio recorded and transcribed verbatim (including pauses). A trained coder (C.V.) coded all interview transcripts and classified participants as secure, dismissive, preoccupied, or unresolved, which allowed us to categorize participants as either securely or insecurely (dismissive, preoccupied, unresolved) attached (i.e., our main two categories of interest). A second trained coder (T.N.) independently coded 25% of interviews. Agreement between the two coders was perfect (Cohen's kappa = 1) for the secure vs. insecure classification. Six participants did not attend the AAI session; hence, $n = 38$ participants were included in these analyses.

Self-report measure of adult attachment style (Experiences in Close Relationships Revised – ECR-R). The ECR-R comprises 36 items rated on a 7-point scale (1 = strongly disagree and 7 = strongly agree) regarding the general experience of intimate adult relationships; 18 items pertain to attachment anxiety (e.g., "I'm afraid that I will lose my partner's love.") and 18 to attachment avoidance (e.g., "I don't feel comfortable opening up to romantic partners.")[57]. Item responses are averaged (after reverse-scoring appropriate items) separately for each subscale to produce a mean score for attachment anxiety and attachment avoidance, with higher scores denoting greater attachment insecurity. This dimensional scoring is in line with research indicating that adult attachment styles are best conceptualised as dimensional constructs[67]. The ECR-R is well-validated[55,68] and demonstrates excellent internal consistency: Cronbach's $\alpha = 0.91$ for attachment anxiety and $\alpha = 0.90$ for attachment avoidance in the present sample.

Statistical analyses. All analyses were carried out in Stata 14[69]. Parametric analyses were conducted after inspecting the distribution of the data. For ease of reference, details on each analysis conducted are presented with the corresponding results below.

Results

Descriptive statistics and Preliminary Analyses. *CT-Optimal and Non-CT Optimal Touch Perception.* Pleasantness ratings showed an inverted U-shaped pattern commonly observed for these velocities (see e.g.[34]: ratings were lowest for velocities at either end of the velocity spectrum (i.e., the 0.3 cm/s^{-1} and 27 cm/s^{-1} velocities), and highest for the intermediate velocities (i.e., 3 cm/s^{-1} and 9 cm/s^{-1}, see Fig. 1). A repeated measures ANOVA showed that velocity was associated with pleasantness ratings, $F(3, 129) = 59.46$, $p < 0.001$, with Sidak-corrected pairwise comparisons indicating that velocities differed significantly from each other ($p < 0.001$) except for the two CT optimal velocities (3 cm/s^{-1} vs. 9 cm/s^{-1}, $p = 0.999$) and the two non-CT-optimal velocities (0.3 cm/s^{-1} vs. 27 cm/s^{-1}, $p = 0.807$). Therefore, we computed mean ratings for CT-optimal vs. non-CT-optimal velocities by calculating the average of ratings for 3 cms^{-1} and 9 cms^{-1} speeds, and 0.3 cms^{-1} and 27 cms^{-1} speeds, respectively. A paired-samples t test showed that CT-optimal vs. non-CT-optimal velocities differed as expected, paired-samples $t(43) = 11.41$, $p < 0.001$, with CT-optimal velocities perceived as more pleasant ($M = 48.43$, $SE = 3.34$) than non-CT-optimal velocities ($M = 3.55$, $SE = 3.74$).

Interoceptive (Cardiac) Accuracy. Mean (*SD*) interoceptive accuracy was 0.42 (0.25). The obtained mean score was slightly lower than mean scores in previous studies using this paradigm (e.g.[30,60]).

Relationship Between CT-Optimal vs. Non-CT Optimal Touch Discrimination and Interoceptive (Cardiac) Accuracy. CT-optimal vs. non-CT optimal touch discrimination (operationalised as a difference score of CT-optimal velocities minus non-CT-optimal velocities, i.e., greater scores denoting higher pleasantness ratings for CT-optimal vs. non-CT-optimal touch) was not significantly correlated with interoceptive (cardiac) accuracy, $r = 0.21$, $p > 0.05$.

		b	*SE*	*p* value	95% CI lower	95% CI higher
AAI	Velocity (CT-optimal vs. Non-CT-optimal)	49.01	4.08	**<0.001**	41.12	57.00
	AAI (security vs. insecurity)	21.72	9.53	**0.023**	3.05	40.40
	Velocity by AAI	−20.82	9.37	**0.026**	−39.19	−2.45
ECR-R	Velocity (CT-optimal vs. Non-CT-optimal)	44.30	3.53	**<0.001**	37.39	51.21
	ECR-R anxiety	5.04	3.95	0.202	−2.71	12.78
	ECR-R avoidance	−3.92	4.21	0.352	−12.16	4.33
	Velocity by ECR-R anxiety	−8.93	3.90	**0.022**	−16.58	−1.28
	Velocity by ECR-R avoidance	−2.09	4.14	0.614	−10.20	6.02
	ECR-R anxiety by ECR-R avoidance	−0.25	2.88	0.932	−5.89	5.40
	Velocity by ECR-R anxiety by ECR-R avoidance	1.27	2.86	0.656	−4.33	6.88

Table 1. Model results for effects of attachment on the perception of affective touch. Note. AAI = Adult Attachment Interview; ECR-R = Experiences in Close Relationships – Revised questionnaire.

Attachment Classifications and Dimensions. Based on the AAI, our sample ($n = 38$) showed the following classification frequencies: $n = 30$ participants (79%) were classified as securely attached and $n = 8$ (21%) as insecurely attached, of whom $n = 1$ (3%) was preoccupied, $n = 5$ (13%) were dismissing, and $n = 2$ (5%) were unresolved. Despite an overrepresentation of securely attached individuals, our sample is in line with the general population AAI norms for non-clinical adult mothers[65] as well as non-clinical adolescents/students[70], also suggesting a larger proportion of dismissive vs. preoccupied individuals. Mean (*SD*) ECR-R dimensional anxiety scores = 2.99 (0.98) and avoidance scores = 3.03 (0.93); in relation to general population norms for women, our sample fell below the mean for anxiety (population norm $M = 3.56$, $SD = 1.13$) and above the mean for avoidance (population norm $M = 2.92$, $SD = 1.21$; see information by Fraley, 2012: http://internal.psychology.illinois.edu/rcfraley/measures/ecrr.htm). ECR-R dimensions were moderately correlated with each other, $r = 0.49$, $p < 0.001$, and were mean centered in statistical analyses to minimize multicollinearity issues[71].

The Relationship between Categorical and Dimensional Measures of Attachment Style. A MANOVA with ECR-R anxiety and ECR-R avoidance scores as outcome variables and AAI classification (secure vs. insecure) as the independent variable showed that ECR-R scores did not differ by AAI classification, $F(2, 36) = 1.74$, $p = 0.191$, Wilk's lamda = 0.910. In other words, it was not the case that ECR-R anxiety scores were significantly lower in the secure vs. insecure group (Secure: $M = 2.87$, $SD = 0.98$; Insecure: $M = 3.37$, $SD = 0.78$), or that ECR-R avoidance scores were significantly lower for securely vs. insecurely attached participants (Secure: $M = 3.05$, $SD = 1.00$; Insecure: $M = 2.90$, $SD = 0.71$). This result supports the choice of two separate measures for the multi-dimensional construct of attachment style.

The Relationship between Measures of Attachment and Interoceptive Accuracy. AAI classification was not associated with interoceptive accuracy, $F(1, 35) = 0.45$, $p = 0.505$. In addition, neither ECR-R anxiety ($r = -0.05$, $p > 0.05$) nor ECR-R avoidance scores ($r = 0.13$, $p > 0.05$), were significantly correlated with interoceptive accuracy, as predicted.

Main Analyses. *Association between interview-assessed attachment style (AAI classification) and the perception of CT-targeted touch.* To examine whether attachment classification as measured by the AAI was associated with the perception of CT-targeted touch, we specified a multilevel regression model with mean pleasantness rating as the outcome variable and velocity (CT-optimal vs. non-CT-optimal), AAI (security vs. insecurity), and their interaction as predictor variables, and controlled for interoceptive accuracy. A random effect was included to account for the repeated assessment of the outcome variable within individuals.

AAI classification predicted pleasantness ratings across velocities: insecurely attached participants rated touch as more pleasant ($M = 34.52$, $SE = 7.46$) than did securely attached participants ($M = 23.21$, $SE = 3.59$). More critically, the hypothesised velocity by AAI interaction was significant (see Table 1 for full model results). Follow-up tests (contrasts) showed that the difference between CT-optimal and non-CT-optimal velocities was significant for securely attached participants ($b = 49.01$, $SE = 4.08$, $p < 0.001$), and insecurely attached participants ($b = 28.19$, $SE = 8.44$, $p = 0.001$). However, the difference in pleasantness ratings for CT-optimal and non-CT-optimal velocities was smaller for insecurely vs. securely attached participants (see adjusted mean difference above and Fig. 2, top panel): An independent samples t-test on the CT-optimal-touch minus non CT-optimal touch difference score (see above for how this was computed) confirmed that the difference was smaller in the insecure group ($M = 28.81$, $SD = 14.13$) than the secure group ($M = 49.01$, $SD = 4.85$), $t(36) = 2.06$, $p = 0.047$. Therefore, although both groups were able to discriminate between the two forms of touch, attachment insecurity was associated with reduced discrimination between CT-optimal and non-CT-optimal touch, in line with our hypothesis.

Association between questionnaire-assessed attachment style (ECR-R) and the perception of CT-targeted touch. To test whether attachment style dimensions as measured by the ECR-R questionnaire were associated with the perception of pleasant touch, we specified a multilevel regression model with mean pleasantness rating as the

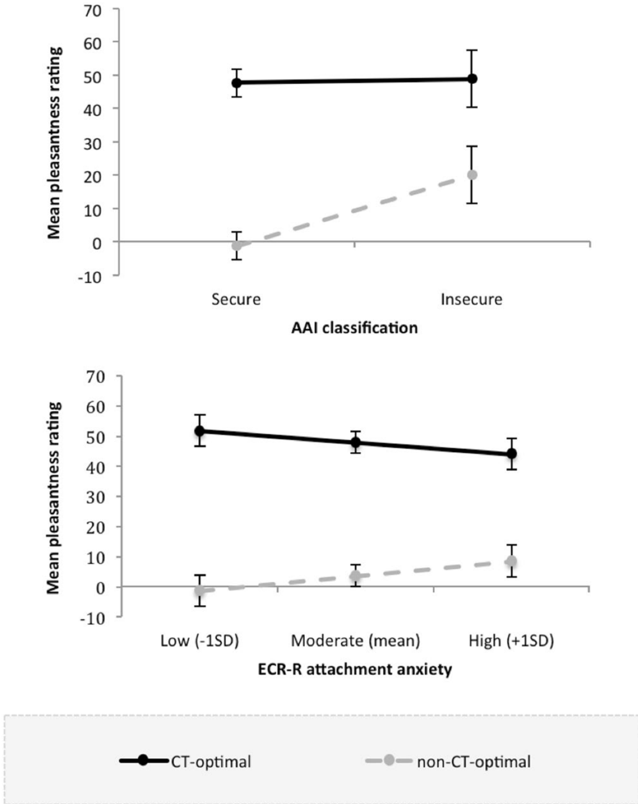

Figure 2. Interactions between velocity (CT-optimal vs. non-CT-optimal) and attachment classification on the Adult Attachment Interview (AAI; top panel), and velocity and attachment anxiety measured using the Experiences in Close Relationships – Revised questionnaire (ECR-R; bottom panel). Error bars represent ±1 standard error of the mean.

outcome variable, and velocity (CT-optimal vs. non-CT-optimal), ECR-R attachment anxiety, ECR-R attachment avoidance, as well as all interaction terms, as predictor variables, and again controlled for interoceptive accuracy. As above, a random effect was included to account for the repeated assessment of the outcome variable within individuals.

Neither attachment anxiety nor attachment avoidance, nor the interaction between the two dimensions were associated with pleasantness ratings across velocities, indicating that pleasantness of touch in general was not influenced by continuous attachment style scores. However, importantly, the hypothesised velocity by attachment anxiety interaction was significant (see Table 1 for full model results). Follow-up analyses revealed that the difference between CT-optimal and non-CT-optimal velocities was significant at lower (i.e., −1SD; $b = -53.06$, $SE = 5.12$, $p < 0.001$), moderate (i.e., mean; $b = -44.32$, $SE = 3.52$, $p < 0.001$), and higher (i.e.,+1 SD; $b = -35.58$, $SE = 5.24$, $p < 0.001$) levels of attachment anxiety. Similar to the AAI results, the difference in pleasantness ratings between CT-optimal and non-CT-optimal velocities was smallest at higher levels of attachment anxiety (see adjusted mean difference above and Fig. 2, bottom panel). This finding indicates that higher attachment anxiety was associated with reduced discrimination between CT-optimal and non-CT-optimal touch. The velocity by attachment avoidance interaction was non-significant, as was the three-way velocity by attachment anxiety by attachment avoidance interaction. Thus, attachment avoidance was not associated with the perception of CT-optimal versus non-CT optimal touch, either alone or interaction with attachment anxiety. In sum, partially supporting our hypothesis, higher attachment anxiety but not attachment avoidance was associated with reduced sensitivity to CT-targeted touch.

Discussion

We reported a novel study investigating the association between attachment styles and CT-optimal touch in adulthood. Under the assumption that CT-optimal touch supports affiliative bonds and social cognition, we assessed how affective-cognitive models of social relating (i.e., attachment) influence the perception of CT-targeted touch. Using the gold-standard assessment of adult attachment (the Adult Attachment Interview; AAI), we found that insecure attachment was associated with reduced discrimination between CT-optimal vs. non-CT optimal touch. This semi-structured interview yields categorical attachment classifications in an implicit way, relating to representations of childhood experiences with caregivers. Acknowledging the different traditions in measuring attachment and the multi-dimensionality of this construct, we also used a well-validated self-report questionnaire that pertains to explicit evaluations of close relationships and takes a dimensional rather than categorical approach. This measure showed that higher attachment anxiety, though not higher attachment avoidance, was associated with reduced discrimination between CT-optimal vs. non-CT optimal touch. Attachment style as assessed by both measures was not related to cardiac perception accuracy, suggesting that attachment is not relevant to all interoceptive modalities in the same way. These results will be discussed in turn below.

We found that both secure and insecure attachment groups (assessed by the AAI) were able to discriminate between CT-optimal vs. non-CT optimal touch. However, the insecure attachment group was significantly worse in this discrimination than the secure group, suggesting that differences in pre-existing models of social interaction and related top-down expectations contribute to individual differences in CT-based touch perception. This finding provides further support to theoretical proposals regarding an association between the perceived affectivity of touch and social affiliation[21,32,46,52]. Attachment representations are thought to originate in early caregiving experiences, in which touch plays a central part[9,10]. There is also evidence that childhood patterns of social relationships may be reinforced across the lifespan[5], and it thus appears that affective responses to touch are also carried into adulthood. In fact, recent evidence suggests that individuals who experience low exposure to touch in everyday life are worse at discriminating CT-targeted touch, and the reasons behind experiencing less tactile exposure seem to relate to a lack of tactile, enjoyable experiences with close, familiar others[58], which may be related to attachment.

Differences in attachment (as measured by the AAI) were not related to cardiac accuracy. To date, there is no evidence to suggest that cardiac accuracy is an interoceptive modality relevant to social affiliation, and thus pre-existing models of social relating, such as attachment classifications, were not predicted to influence this interoceptive modality. This finding also speaks to the more general relationship between interoceptive modalities. In other studies, we have shown that the perception of CT-optimal touch and cardiac perception accuracy are unrelated[30], even though heart rate decreases have been associated with affective touch[47]. The current findings confirm this and further suggest that differences in attachment relate to the perception of CT-optimal touch, but not cardiac perception accuracy.

Turning to our second, two-dimensional measure of attachment style, we found that higher scores in attachment anxiety were related to poorer discrimination between CT-optimal and non-CT optimal touch. This finding suggests that anxious attachment style as assessed by an explicit measure of adult close relationships relates to the perceived affectivity of touch in a similar way to insecure attachment as assessed by the AAI. In insecure attachment, others are perceived as unreliable and inattentive, and particularly in anxious insecure attachment this might generate anxiety[72]. These kinds of social expectations might thus affect the way in which CT-optimal touch is perceived and enjoyed. Consistent with recent research suggesting that infants as old as two months show selective sensitivity to CT-targeted touch[73,74], we hypothesized that any difference in this discrimination in adulthood based on attachment styles would relate to top-down effects. Indeed, we also observed that insecure attachment style was related to the overall perceived pleasantness of our tactile stimuli, irrespective of whether or not they were in the CT-optimal range.

The fact that we did not observe differences in discrimination in our questionnaire dimension of attachment avoidance was unexpected, particularly as these individuals are characterized by a need for emotional distance and reduced proximity seeking, including touch[55,75,76]. This null finding thus suggests that at least at an explicit level, current top-down representations of close relationships in these individuals may not determine the perceived affectivity of touch. However, future research is needed before drawing firm conclusions. Here, we propose a few candidate explanations that may have led to such a lack of findings. First, although measurements of attachment style may possess benefits at a theoretical and statistical level, self-reported questionnaires have been largely criticized for being passive (i.e., not detecting attachment phenomena that need to be activated to be manifested[55]). As such, this may have contributed to the current lack of findings. Also, as self-report measures, they are subject to social desirability effects, which are likely to be more pronounced in more avoidantly attached individuals.

Finally, as with our other, implicit measure of attachment, we found that individual differences in attachment style (as measured by the questionnaire dimensions) were not related to cardiac accuracy, suggesting that cognitive more models of current close social relationships and related top-down expectations do not contribute to individual differences in cardiac interoceptive perception. Given that individual differences in attachment style were related to the perceived affectivity of the touch and not cardiac accuracy, this finding provides further support to the specificity of the relationship between CT-optimal touch and attachment style.

Our findings should be considered in light of their limitations and directions for future research. First, it should be noted that there were no differences in the attachment anxiety or avoidance questionnaire scores between the secure and insecure AAI groups. This finding, together with prior research suggesting a trivial to small relation between self-report measures of attachment and the AAI[77], speaks to the different aspects captured by each of these measures and consequently supports the choice of two separate measures for this multi-dimensional construct.

Second, on the AAI, small numbers in the insecure attachment group meant we were unable to further compare preoccupied vs. dismissing individuals. Future studies could aim to recruit larger groups of preoccupied and dismissing individuals to examine whether results in the insecure group may have been driven by preoccupied or dismissive individuals (although interestingly, the largest subgroup in the insecure AAI classification was dismissive; in line with the general population AAI norms[65,70]).

Third, pleasantness ratings for the CT-optimal touch velocities overall fell in the middle of the positive side of the response scale; it is likely that touch by an attachment figure, such as the romantic partner, may feel even more pleasant to participants than touch by an experimenter. It is clear that many social, environmental factors, including the relationship with the touch provider, can influence the perception of CT-optimal, affective touch (see[78] for a discussion). For instance, although the effects on perceived pleasantness between a person versus a robot delivering the touch seem to be comparable[79], evidence suggests that at least in romantic partners, the perception of pleasantness depends on the quality of their relationship[80], thereby highlighting the importance of the quality of interpersonal interactions in touch perception. Similarly, the current effects on CT-optimal vs. non-CT optimal touch discrimination may be subject to social context, in which for instance, touch by an attachment figure could activate attachment behaviors that are not at display when strangers are involved (see[55]). Thus, future research could incorporate partner-administered touch.

Finally, we only tested women in order to control for gender effects associated with the perception of touch (e.g.[62,81–84]; but see[85–87]); however, future research is needed to examine whether the present results extend to men. In particular, given that men tend to show higher attachment avoidance and lower anxiety than women (see[88] for a meta-analysis), one may speculate about gender effects when looking at CT-targeted touch sensitivity in relation to attachment style. Whether or not these exist, and whether they may thus account for the mixed findings in the literature regarding general gender effects in touch perception, needs to be examined by future research.

In sum, the present study corroborates and extends previous literature on the affectivity of touch and its relation with affiliative bonds and social cognition. Given that attachment style (in both measures) was not related to perceived cardiac accuracy, these findings point to the specificity of the relationship between CT-optimal touch and attachment style. Future work is needed to examine the role of social context and whether the present results extend to men.

Data Availability

The datasets generated during and/or analysed during the current study are available from the corresponding author on reasonable request.

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Acknowledgements
We are grateful to Nadia Blom, Amanda Hornsby and Isabel Rafferty for their help in transcribing the adult attachment interviews, and to Nikolaos Tzikas and Elena Panagiotopoulou for his help in conducting several of the interviews. This study was supported by a project grant (no. II/85 069) from the Volkswagen Foundation 'European Platform for Life Sciences, Mind Sciences and Humanities' and a European Research Council Starting Investigator Award (ERC-2012-STG GA313755) (to A.F.). A.F.'s time was also partly supported by an ApsaA research grant. T.N. is supported by the Wellcome Trust Principal Research Fellowship of Professor Read Montague. M.V.M. is supported by the National Council on Science and Technology (CONACyT-538843; Mexico) scholarship.

Author Contributions
C. Krahé, A. Gentsch and A. Fotopoulou developed the hypothesis and research plan. L. Guy collected the data. C. Vari and T. Nolte coded the interviews. C. Krahé and M. von Mohr analyzed the data. C. Krahé and M. von Mohr wrote the manuscript, under the guidance of A. Gentsch, C. Vari, T. Nolte and A. Fotopoulou. All authors approved the final version of the manuscript for submission.

Additional Information
Competing Interests: The authors declare no competing interests.

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